Smart Hydroponics: IoT and ML-Driven Sustainable Farming

FYP Interim Report

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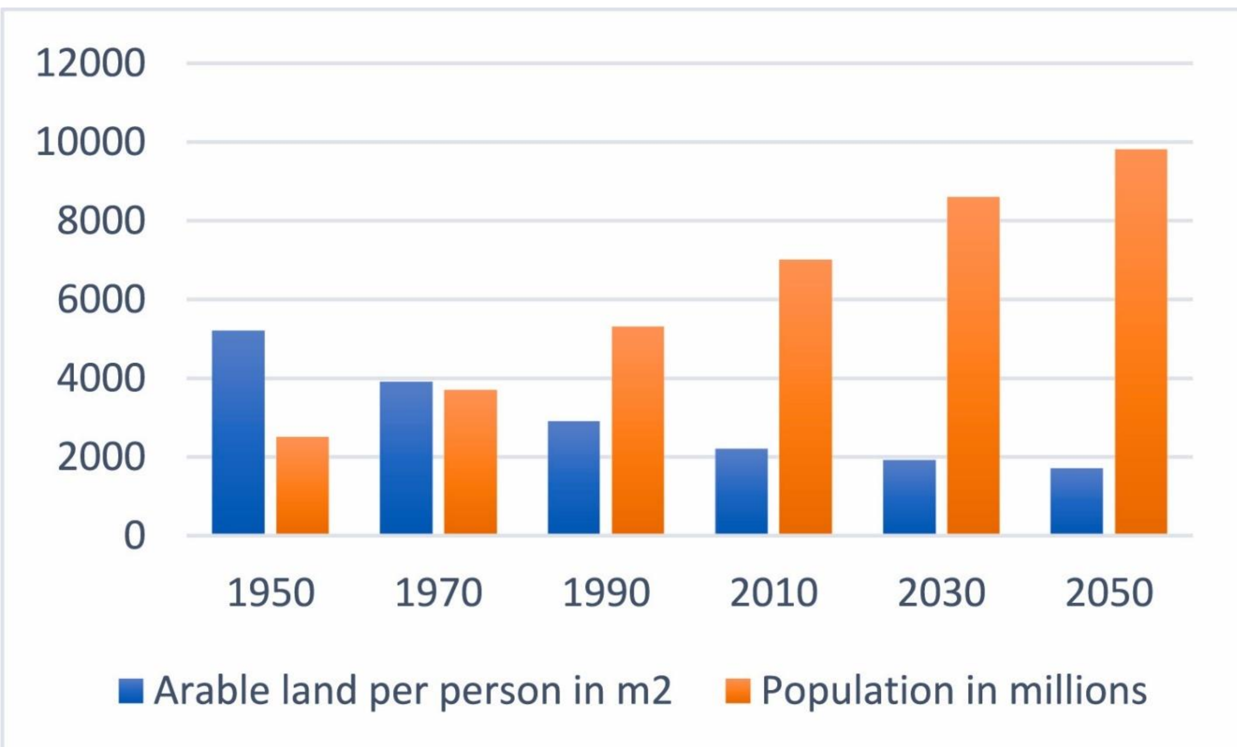
1. Abstract

The integration of Internet of Things (IoT) and Machine Learning (ML) into hydroponic farming systems has revolutionized sustainable agriculture. Our project aims the development of a smart hydroponic system that uses IoT for real-time monitoring and Machine Learning for predictive analytics to optimize plant growth, resource efficiency, and sustainability. By analyzing existing research, this report highlights the advancements, and future directions of IoT and ML-driven hydroponic systems. The findings demonstrate the potential of these technologies to enhance crop yield, reduce water and nutrient consumption, and enable precision farming.

2. Introduction

Over the years there has been a continuous swelling in the population of the world which has a significant impact on the food supply. The world population is expected to reach up to 9.7 billion in 2050. The situation is more critical for Pakistan, as it is the fifth most populated country in the world with a population of 250 million. Cultivable and arable land is getting smaller due to a sharp hiking population and rising food demands. According to reports, between 1963 and 2009, the amount of land needed for agriculture increased by 42 percent. With an estimated population up to 2050, the globe would need to produce 50 % more food, which will require additional arable land that will simply not be accessible. The amount of arable land per person is predicted to be less than 0.20 ha by 2050, which is less than a third of what it was in 1970 as shown below. [1]



Thus, food production by conventional agriculture system is today's real challenge. VF technique is one of the substantial solutions that could be used in place of soil-based farming systems as a supplementary approach to address the ongoing scarcity of water and fertile agricultural land. Hydroponics, a soilless farming technique, has gained significant attention due to its ability to conserve water, reduce land usage, and enable year-round cultivation. However, traditional hydroponic systems often lack real-time monitoring and adaptive control, leading to inefficiencies in resource utilization. The advent of IoT and ML has opened new avenues for automating and optimizing hydroponic systems. IoT enables the collection of real-time data on environmental parameters such as temperature, humidity, pH, and nutrient levels, while ML algorithms can analyze this data to predict optimal growing conditions. This project aims to design a smart hydroponic system that integrates IoT and ML to achieve sustainable and efficient farming.

3. Literature Review

3.1 Overview of Hydroponic System

Hydroponics is a method of growing plants without soil, using a nutrient-rich water solution to deliver essential minerals directly to the plant roots.

3.1.1 Types of Hydroponics

There are around 11 different methods of hydroponics and vertical farming followed around the globe. The most followed methods are given below:

3.1.1.1 Aeroponics

It is an air and water culture growth method where plant roots get suspended in the air and receive atomized nutrients and water.

In our project, we are using the aeroponics technique.

3.1.1.2 Deep Water Culture (DWC)

In this method, the plant's roots are dipped directly inside the nutrient tank so that oxygen and nutrients are absorbed by the plant easily. An air stone has been fitted for the supply of oxygen directly to the system.

3.1.1.3 Ebb and flow system

In this system, plant pots are filled up by media, like rock wool that serves as a provisional nutritional solution tank as well as an anchor for roots. A nutrient solution from the tank is poured into a grow bed by a water pump until this solution reaches a specific level and stays at the grow bed for a particular time interval.

3.1.1.4 NFT (Nutrient Film Technique)

The nutrient solution goes into the grow tray using a motor pump and this solution circulates throughout the entire system. The excess nutrients can drain back into the reservoir as the grow tray is designed in a slanted manner.

Table 1: Comparison of Vertical Farming Techniques [5]

Parameters	Other Hydroponic Systems	Aeroponic System

Productivity (yield/sq.m/year)	150-200 kg	200-250 kg
Water saving percentage	Upto 90%	Upto 95%
Space utilization efficiency	Upto 90%	Upto 95%
Resource requirements	Nutrient rich water, Grow lights, Growing medium(optional)	Misting nozzles, Nutrient richwater solution, Grow lights

3.2 Related Work

Harn Tung Ng, Zhi Kean Tham, Nurul Amani Abdul Rahim at Universiti Sains Malaysia (2023) implemented an IoT-enabled vertical farming system using low-cost embedded microcontrollers (Arduino Nano and NodeMCU ESP8266 Wi-Fi module) and sensors, including DHT22 for temperature and humidity, capacitive soil moisture sensors, and UV LED lights, to monitor and control environmental parameters such as soil moisture, air humidity, and temperature. The system utilized a 12V 4-channel relay module to control water pumps and UV lighting, while an HC4067 multiplexer enabled multiple soil moisture sensors to share a single analog input pin. Data was collected and transmitted to the Blynk cloud via HTTP REST API, and a user interface (UI) was developed using G web development software and hosted on the SystemLink cloud, allowing real-time monitoring and control through any web browser or smart device. The system achieved precise control over irrigation and UV light exposure, with soil moisture levels and environmental conditions displayed numerically and graphically on the UI, updated every 10 seconds.[2]

Muhammad E. H. Chowdhury, Amith Khandak, Saba Ahmed and Fatima Al-Khuzaei at Qatar University, Doha Qatar (2020) developed an automated vertical hydroponic system using a Nutrient Film Technique (NFT) structure consisting of 3 shelves with 4 polyvinyl chloride (PVC) pipes per shelf, each containing 9 planting holes, and a 46 L nutrient container made of light-blocking plastic to prevent algae growth. The system incorporated a SUNSUN submersible water pump (600 LPH) for water circulation, LED lights (6K3R4 and K6) for optimal photosynthesis, and a nutrient solution from Fox Farm, along with pH adjustment solutions from General Hydroponics. Sensors such as Atlas Scientific pH and EC sensors, a YF-S201 water flow sensor, a capacitive water level sensor, and temperature and humidity sensors were integrated with an Arduino Mega microcontroller for real-time monitoring and control. The system utilized dosing pumps for nutrient and pH adjustment, an ESP8266 Wi-Fi module for IoT connectivity, and the Thingspeak platform for data visualization and storage. Power consumption was monitored using a custom power meter with ACS712 current and ZMPT101B voltage sensors, while an air conditioning subsystem maintained optimal temperature (19–28 °C). The system achieved efficient plant growth with a monthly water consumption of 8–10 L successfully maintaining stable pH (5.0–7.5) and EC levels. It also featured an SMS alert system for pump failures and demonstrated the ability to grow mint, lettuce, tomato, cucumber, and other plants, offering a cost-effective, scalable, and user-friendly solution for indoor hydroponic farming.[3]

Binoy Sasmal, Gobinda Das and Preeti Mallick at national institute of technology arunachal Pradesh, India (2024) developed a vertical farming (VF) system using a combination of IoT sensors, machine learning (ML) algorithms, and advanced agricultural technologies to address challenges in traditional farming. Key components included IoT sensors for monitoring pH, electric conductivity (EC), light intensity, humidity, temperature, and soil moisture, with data stored and analyzed in the cloud for real-time decision-making. Image recognition techniques, such as Convolutional Neural Networks (CNN) and YOLO (You Only Look Once), were employed for disease detection in crops, using image augmentation methods like rotation, intensity adjustment, and flipping to enhance dataset quality. Ultrasonic sensors were used to measure plant height and optimize light exposure, while robotic navigation systems with linear bearing rods and cameras enabled precise plant monitoring and movement within the VF structure. The system also incorporated artificial lighting using LED lights and LDR sensors to maintain optimal light intensity, and CMOS cameras for tracking plant growth stages. For energy efficiency, renewable energy sources like solar panels and geothermal systems were integrated. The system achieved high accuracy in disease detection (97.71% using CNN). [4]

Rajendiran G and Rethnaraj J at SRM Institute of Science and Technology (2023) developed a hydroponic system using IoT sensors to monitor critical parameters such as pH, electric conductivity (EC), light intensity, humidity, and temperature, integrated with machine learning algorithms like Artificial Neural Networks (ANN), Random Forest (RF), and Support Vector Regression (SVR) for data analysis and yield prediction, achieving an accuracy of 89.18%. The system utilized a nutrient-rich water solution as the growing medium, eliminating the need for soil, and incorporated automated controls for nutrient delivery and environmental conditions. Key components included submersible water pumps, LED grow lights, and dosing pumps for pH and nutrient adjustments, while the IoT platform enabled real-time data collection and remote monitoring via cloud-based systems like Thingspeak. The hydroponic system demonstrated significant advantages, including precise control over nutrient delivery, reduced water usage (up to 90% compared to traditional farming), minimized chemical usage, and increased crop yield, while growing leafy greens, herbs, strawberries, tomatoes, cucumbers, and peppers. [5]

Table 2: Performance Assessment of Vertical Farming Techniques.[5]

VF technique	Data Collection	ML Algorithm	Accuracy	Advantages	Applications
Aeroponics	IoT sensors (pH,EC,light,)	RF XGBoost	94.37%	Precise control over the nutrient delivery	Herbs, lettuce, cabbage, carrots, tomatoes, leafy
Aquaponics	IoT sensors (pH, EC,light, humidity, temperature)	Decision trees RF LR	91.28%	Minimize water usage, utilize fish waste as nutrientsource, high crop yield	Garlic, Chives, carrots, mint, water cross

Other Hydroponics	IoT sensors (pH, EC,light, humidity, temperature)	ANN RF SVR	89.18%	Precise control over the nutrient delivery and environmental conditions, Reduces water usage, increased crop yield, minimizes chemical usage	Leafy greens, herbs, strawberries, tomatoes, cucumbers, peppers

4. Work Done So Far

4.1 3D Model of Hydroponic

The 3D model of hydroponic systems (aeroponics) was developed using SolidWorks software.

4.2 Dimensions of Hydroponic Structure

Plant Cup (Total = 96)

Diameter = 40 mm
Length = 50 mm

PPRC Pipe (water) (0.5 inch)

Pipe Length = 8 inch
Quantity = 4

PPRC Center Pipe (0.5 inch)

Pipe Length = 1.7 m

4 Inch Elbow

Quantity = 4

Elbow & Tee connector pipe (4 inch)

Pipe Length = 1 ft
Quantity = 7

Pipe b/w T & elbow (0.5 inch)

Pipe Length = 21 inch
Quantity = 6

PVC Elbow (0.5 inch)

Quantity = 4

4 Inch Pipe End Cap

Quantity = 5

Plant Holes Tower/Pipe (4 inch)

Pipe Length = 1.5 m
Quantity = 4
Hole diameter = 40 mm
(8 holes Vertically & 3 holes horizontally = 24 in each pipe)

4 Inch Tee

Quantity = 3

0.5 Inch Pipe Tee

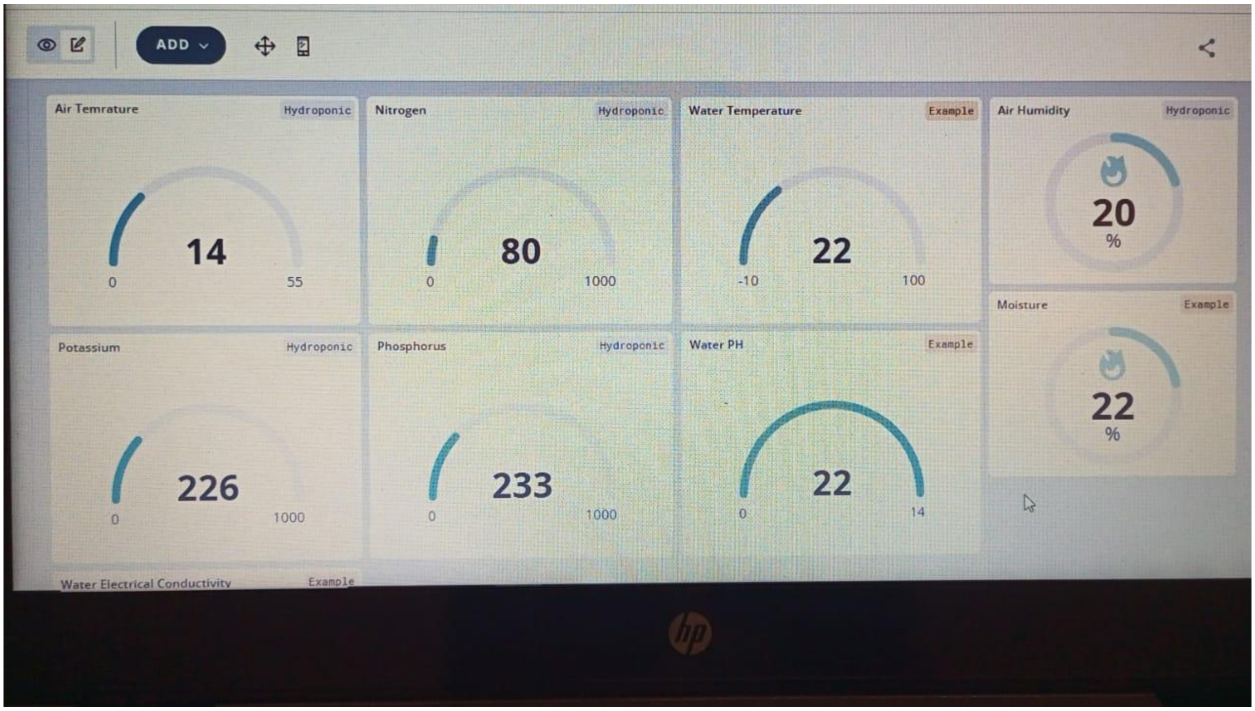
Quantity = 3

4.3 Hydroponic Structure

The following hydroponic structure has been developed and designed, according to the above dimensions, in workshop using all the necessary equipment and tools like heater gun, pprc heater, hacksaw.

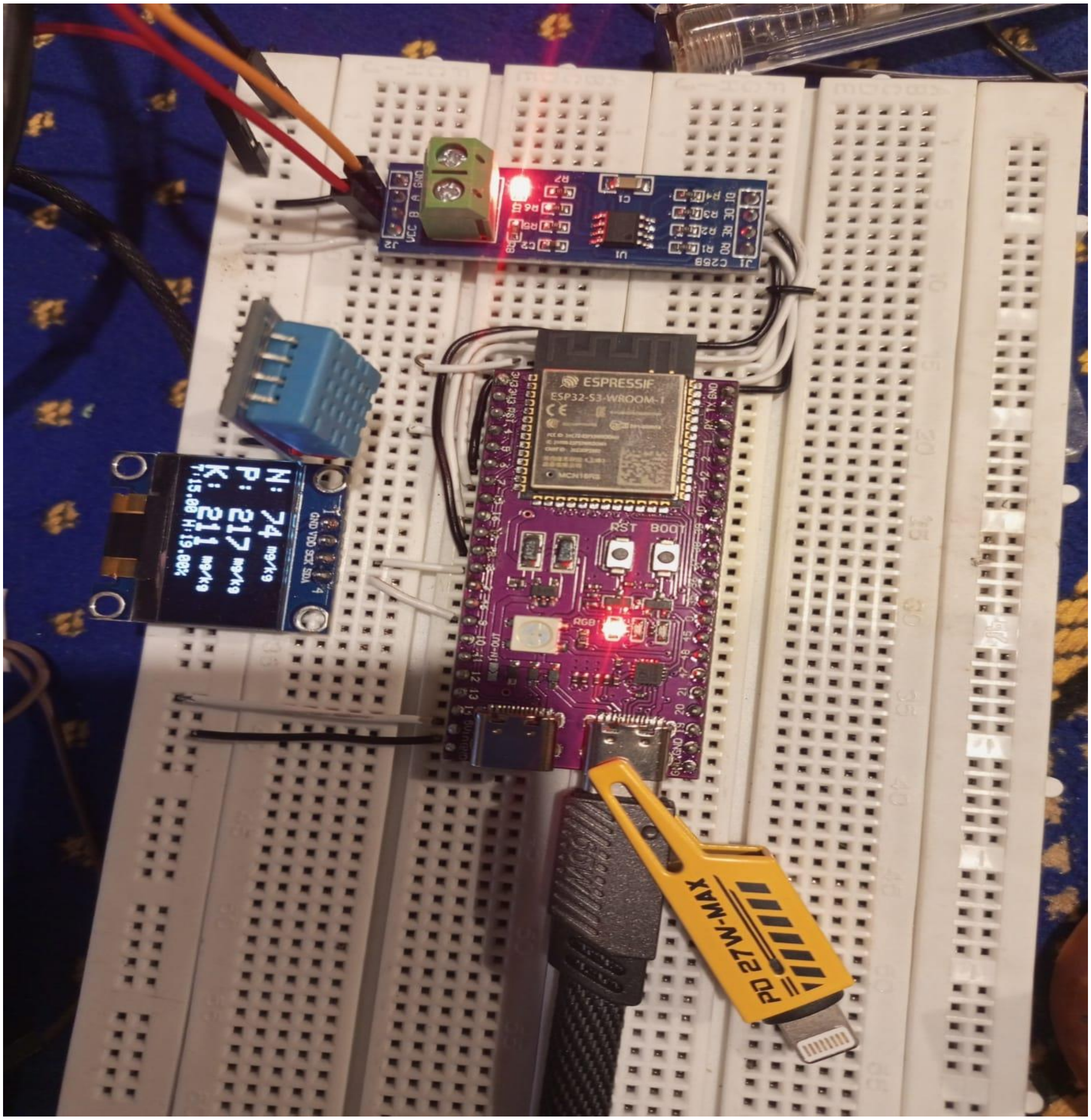
4.4 Arduino Dashboard

The dashboard is created using Arduino cloud which displays the Air Temperature, Nitrogen, Water Temperature, Air Humidity, Potassium, Phosphorus and pH values as shown below:



4.5 Circuit

The circuit made till now is shown below and further modification is required in it.



5. Way Forward

5.1 Targeted Plants

Plant Name	pH	Electrical Conductivity	Timeline (Weeks)
Lettuce	5.5 – 6.5	0.8 - 1.2	2 – 12
Cocumber	5.8 – 6.0	1.7 – 2.5	7 – 12
Capsicum	6.0 – 6.5	1.8 – 2.2	8- 14
Tomato	5.5 – 6.5	2.0 – 5.0	8 – 14

Eggplant	5.5	2.5 – 3.5	8 - 12

5.2 IoT Circuit Implementation on Hydroponic

Our future work would include the process of growing the above targeted plants in hydroponic system, integrating IoT-based monitoring and control circuit into it. We aim to enhance the precision in nutrient delivery, water usage and environmental control to ensure optimal plant growth.

5.3 Data Collection and Machine Learning

After integrating IoT circuit with hydroponic system, we would collect real-time data through IoT sensors like NPK, pH, Electrical Conductivity, TDS, Water Temperature, Air Temperature and Humidity and store it on google cloud. This data will further be used for training machine learning algorithm to predict plant growth.

6. References

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